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ARMSTRONG LABORATORY

A SPECIAL-PURPOSE VIRTUAL AUDIOMETER

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A Virtual Audiometer is described. The audiometer is designed so that the users can measure their own thresholds and binaural loudness balances in a moderately noisy environment for a range of frequencies from 250 to 6000 Hz. Operator supervision required is minimal. The audiometer is constructed with a computer-assisted software engineering base called LabVIEW. Several user-aids are available from the virtual Front Panel of the instrument that contribute to the accuracy of the subject's determinations. The organization of the virtual instrument is illustrated and discussed. Sample data from four subjects of contrasting ages are included.

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A SPECIAL-PURPOSE VIRTUAL AUDIOMETER

SUMMARY

The audiometer described in this report represents only one organization of the Macintosh computer. The computer can, of course, be organized in many other ways; e.g., as a word processor, a teaching machine, etc. With computer-assisted software, investigators can design their own instruments to solve problems specific to the problem being investigated now, then modify or even discard the software-engineered instrument for the next problem, without incurring the expense of new hardware. Indeed, the audiometer presented here grew from the realization, generated by other studies, that the possibility of sensory-neural hearing loss was real and that recruitment in ears with such losses could alter the perception of image location as compared to normal subjects. With the LabVIEW software, the construction of an audiometer for a specific purpose was a reasonable target. The same hardware is then re-configured to test the larger question of the usefulness of acoustic signals for maintaining spatial orientation.

flight simulator and since the intensities of the acoustic signals will be adjusted for audibility in relation to the ambient sound level, a situational assessment of binaural loudness balance is appropriate. We have used the virtual instruments (VIs) in the LabVIEW system to construct a Virtual Audiometer optimized for a self-administered examination of binaural loudness balance within our test situation.

In its present state the audiometer does not meet the standards cited by Hirsh (1952) for a general purpose device to measure hearing: there is no specification of the acoustic output of the earphone. Instead, the electrical output of the digital to analogue (D/A) converter in the computer is specified in decibels re 1 millivolt (mV). One could easily incorporate the frequency response curve of the earphones into the program. The frequency range of interest in this application is 0.25 - 6.0 kHz. Some variation is expected in acoustic output with a constant input voltage over that range, probably about 5 dB or so. In other respects, our virtual audiometer meets many of the requirements Hirsh established. A noise masker is included and the sound is turned on and off without clicks. Many frequencies can be tested over our range of interest; at present the default increment step is 250 Hz.

OPERATING PROCEDURE

General

After a brief familiarization with the computer and the use of the "mouse", the subject will follow simple written instructions for first setting the frequencies and then the intensities. Several aids for making judgments are available as the subject carries out listening tasks and interacts with the switches and indicators on the Front Panel (Appendix A, p. 16). The intensity setting for the left ear is shown by the slide switch on the upper left side of the panel, and that for the right ear, on the right side. The subject moves the slider and activates the switches by moving the mouse to place the pointer (a small outline drawing of an index finger) on the switch or slider and clicking. The digital control Immediately below the slide switches shows the number to which the slider points. The subject can use the control to set the intensity in 1-dB steps. The control can be calibrated to any precision, but 1 dB is sufficient for the present use. Immediately below the digital control is an indicator which shows the root-mean-square (RMS) value of the voltage. In the upper center of the panel is a labeled toggle switch, **RUN**. To start the program set the **RUN** switch in the upward position. The frequency of the sound is set by the rotary switch just below the **RUN** switch in the center of the Panel. The digital control just below the rotary switch allows the subject to set the frequency within 250-Hz increments.

Below and to the left of the frequency control there is a display labeled **TIME WAVEFORM**. The vertical axis represents voltage; and the horizontal axis, milliseconds. The display of the sine wave may be inhibited by clicking on **DISPLAY** just above the figure. Eliminating the display speeds the operation of the program.

Provision for masking one ear while testing the other is included. The switch for contralateral masking is at the right side of the display, along with a digital control. By clicking the mouse on **Mask Cntra Ear** a lowpass noise is delivered to the contralateral ear; the noise intensity is set by the digital control. If one ear shows a severe hearing loss and the other does not, the possibility arises that the strong acoustic pressure required to test the poorer ear can leak beyond the head phones to be detected at the more sensitive ear. An appropriate level for the noise can be determined by delivering the noise and signal to the same ear (switch not depressed) and setting the masking noise to mask the signal at some level, say 40 dB. The subject would then test the opposite ear with the noise left at that setting. Since such leakage does not occur below relatively high intensities, the addition of the masking noise to the more sensitive ear restricts detection of the signal to the poorer ear.

Below the intensity controls for the right ear is a display labeled **PWR SP** for Power Spectrum. For a sine wave, the display shows a single peak at the x-axis location that corresponds to the frequency. The masking noise is shown as a power spectrum. For the case of signal and noise presented to the same ear, the subject is expected to detect the signal when its peak is just above the level of the noise.

An aid to making a determination of equal loudness in the two ears is the switch labeled **Cntinus?**. When the mouse is clicked on this switch, the sound is delivered to both ears simultaneously; otherwise, the sound is delivered to each ear alternately. One can expect that an equal loudness in the two ears would place the binaural sound image at the center of the subject's head.

Specific

The present view of procedure is straightforward. After the subject indicates confidence in using the mouse, changing frequencies and intensities, and feels comfortable with the earphones, the operator will check their placement (red cord to right ear) and describe the threshold procedure. The subject will find threshold for each ear using the method of adjustment, interacting with the Front Panel. Six frequencies, 0.25, 0.50, 1.0, 2.0, 4.0, and 6.0 kHz, will be tested in a sequence given to the subject by the operator. One expects the average of 1, 2 and 4 kHz to be about 15 to 20 dB better than the threshold at 0.25 kHz and about 5-10 dB better than that at 6 kHz. The operator will verify severe departures from the expected relations among the thresholds.

For each of three frequencies, 0.5, 1.0 and 4.0 kHz, a loudness match at 10, 35 and 60 dB re threshold for the better ear will be carried out in order to estimate the compensation required to center the auditory image. With the **Cntinus?** switch in the inactive position so that the ears are stimulated alternately, the subject will set the frequency and intensity for the better ear and adjust the intensity at the other ear to make the loudness at each ear equal. The dB reading for the loudness match is recorded by the subject. The subject then clicks the **Cntinus?** switch to deliver the sound to both ears simultaneously. The task now is to adjust the intensity for the test ear to center the sound image. There should be little adjustment required. The operator will verify any differences greater than 3 dB.

When the equal-loudness matches and centering judgments for the three intensities at one frequency are completed, the subject will set the next frequency and proceed with the intensity set. The operator will confirm any unusual relations among the intensity settings.

ORGANIZATION OF THE AUDIOMETER

The LabVIEW virtual audiometer is shown in Appendix A. The computer-assisted software displays the program in graphic form. The control objects on the Front Panel are also represented in the block diagrams. The sequence of block diagrams represents the program. The diagrams contain structures, some of which may contain functions, which are expressed as graphic symbols. The first page of the block diagram for the audiometer shows Frames 0 and 1, on page 17. Outside Frame 0, the number of points, the output channels, and the time base for generating the acoustic signal are specified and delivered to the sub-VI, Setup Dbuf, inside Frame 0. Setup Dbuf establishes the output channels and the time base and also includes an error output. There is a digital indicator in the lower right corner of the Front Panel to show the error code that may be output by Setup Dbuf. The only function carried out in Frame 1 is represented by the sub-VI, Start. The sub-VIs Setup Dbuf, Start, BlkLoad and Clear are graphic symbols representing the steps of a sequence called Double-Buffering which supports the output of a continuous waveform. BlkLoad and Clear will be used in later frames.

Frame 2, p. 18, contains the expressions for the Front Panel switches and the operations required to generate the sine wave and noise band waveforms. Within Frame 2 there is another structure, a While Loop, which carries out the operations within it until the **RUN** switch is toggled. The While Loop has a circular arrow in its lower right-hand corner. When the **RUN** switch is in the upward direction, i.e., true, the loop continues and the structures within the loop, Frames 0, 1 and the case statements within them, are cycled. When the case statements within the frames are selected, any frames within them are also cycled. Within the While Loop, the Front Panel switches controlling frequency and intensity are monitored, earphone is selected, and the signal onset and offset is controlled. Shift registers, the small triangles on the right and left edges of the While Loop, store information from one cycle for use in the subsequent cycle. Two sets of shift registers are shown, labeled FRQ and RMS, in order to compare the frequency and voltage in a present cycle to those from the preceding cycle.

Inner Frame 0

At the left side of Frame 0, the sub-VI, Cycles Out, calculates the number of cycles that the signal buffer can contain. This number is taken to a LabVIEW sub-VI that generates a sine pattern containing the number of cycles designated. The sine pattern is multiplied by the pulse pattern (carried forward from (outer) Frame 0) and the amplitude of the resulting pattern is increased 10 times. Two LabVIEW VIs, Gaussian Noise and Low-Pass Filter, are used to generate the low-pass masking noise. The Ear-stimulated indicator is shown in the lower left-hand corner of the frame.

The LabVIEW VIs supporting Double-Buffering for waveform generation produce an interleaving of the two signal channels (one to each ear). In this application, the two channels must be controlled independently. There is provision in LabVIEW for separating the interleaved channels, called "decimating". When the interleaved channels are decimated, one channel is taken to the case statement (upper middle of Inner Frame 0) which implements the **DISPLAY** switch on the Front Panel. If **DISPLAY** is true, the time waveform is displayed. The false case is also included within the frame but is printed below as an empty rectangle on the page immediately below outer Frame 2. False cases can also contain functions as is clear from the other illustrations of case statements shown along with the **DISPLAY** statement. Note that Inner

Frame 1 is also included within the While Loop even though it is displayed separately on p. 19.

To maintain separate treatment of the two signal channels, pairs of case statements must be implemented in Inner Frame 0 (at lower-middle and right). In the lower-middle portion of the frame, the outer case statement is true when the indicator for Ear is zero, corresponding to the left earphone. When the inner case statement is false (the **Cntinus?** switch is not depressed) the voltage to the right earphone is reduced to an intensity below audibility. On the next time through the While Loop, the Ear indicator will be 1, the outer case statement will be false, and if the **Cntinus?** switch is not depressed, the inner case statement will also be false. The intensity to the left ear will be as designated on the Front Panel and that to the right ear will be attenuated. When the **Cntinus?** switch is depressed, the inner case statement will be true for both cases of the outer statement and the intensities for each ear will be as designated on the Front Panel. Similar logic applies to the nested case statements for contralateral masking noise as shown at the lower right portion of Inner Frame 0. Following the case statements, the two separate channels are interleaved again and taken to Inner Frame 1, top of p. 19.

Inner Frame 1

The sine wave signal must be turned on and off carefully in this application. When the signal is turned on or off abruptly a click is produced and, for that brief time, the acoustic energy is spread among a wide range of frequencies. In this event, we cannot be sure that the subject is responding to the frequency indicated on the Front Panel. When the signal is turned on or off gradually, the spread of energy among frequencies is restricted to a narrow band around the frequency of the sine wave. The audiometer program turns the signal on and off gradually by recognizing when the subject changes the frequency, or when the intensity has changed. For each cycle of the While Loop the frequency from the Front Panel is stored in the (upper) shift registers, labeled as FRQ on the right side of the While Loop, p. 18. The second (lower) set of shift registers, labeled RMS, is used to compare the voltage reading from the last cycle with the present one. When the stimulus to the earphones alternates, left and right, the tone is turned off and on gradually. When the **Cntinus?** switch is pressed, the signal is delivered to both ears simultaneously and the successive pulses of the stimulus are detected as the subject varies the intensity.

Within Inner Frame 1, a case statement is used to test whether the frequency for the current cycle of the While Loop differs from that for the last. When the frequencies are different, the case statement is true. Within the true case, there is a sequence of two frames. In Frame 0, a LabVIEW VI, Ramp Function, is configured to decrease from 1 to 0. The signal buffer is multiplied by the ramp function so that the signal intensity decreases from its full value (determined by the Front Panel attenuator) to zero. Then, in Frame 1 the signal amplitude is held to zero for the remainder of the present loop, and the zero RMS is read and stored in the right-hand shift register. The present cycle is completed and the program returns to cycle the While Loop again, incrementing the counter (i), to choose the opposite ear. The Front Panel switches and controls are checked again and the program moves again to Inner Frame 1.

If the frequency has not yet changed, the values in the left and right shift registers are the same and the case is false; but here, the program must recognize whether the signal is off or on. If the signal has been off, (RMS=0) it must be turned on for the new frequency, but if not, the subject is still making a determination and the signal must be maintained at the intensity set by the Front Panel control. This condition requires another case statement within Frame 0. If the signal has not been turned off, the amplitude is kept constant (false case); but if the frequency has changed, the signal is turned off. In Frame 1, within the outer case statement, the signal is kept constant. In each case and frame, the interleaved data are finally taken to Blk LOAD, for output to the earphones. For the conditions in which signal output is steady-state, the data are also taken to the LabVIEW VI, RMS.

When the RUN switch on the Front Panel is toggled to the down position, the connection to the circular arrow in the lower right corner of the While Loop is completed and the program moves to Frame 3. A LabVIEW VI, CLEAR, is called; the Double-Buffering procedure is stopped; and the program stops.

Sub-VIs

New LabVIEW sub-VIs can be created as convenience demands: e.g., to reduce clutter on a diagram, to avoid re-wiring in successive diagrams, etc. The sub-VI, Cycles Out, is such a convenience. In this sub-VI, the number of cycles is determined by frequency, the number of points, and the time base. The sub-VI was created to minimize the use of space in the diagram. Another sub-VI, dB to Volts, references the voltage level of the output to 0.001 V, i.e., 1 millivolt.

PRELIMINARY VERIFICATION OF AUDIOMETER FUNCTION

A test was run with four subjects in a moderately noisy office area. Fan noise and conversational background levels were easily audible. The subjects heard the audiometer signals through Sennheiser (HD520) earphones. Appendix B shows a plot of measurements of auditory thresholds for two young women, MF and CH, ages 20-25 years, and for two older males, DCT and KKG, both over 50 years old. The older males showed elevation in threshold at high frequencies; the older of the two showed greater loss at 3 kHz than the younger. Neither female showed any loss after reaching a minimum at 3 kHz. Presumably the ambient noise at frequencies below 3 kHz elevated the thresholds.

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3. Lyons, T. L., Gillingham. K.K., Teas, D. C., Ercoline, W. E., Oakley, C. The effects of acoustic orientation cues on instrument flight performance in a flight simulator. Aviat Space Environ Med 61:699-706 (1990).
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APPENDIX A

LabVIEW Representation of Virtual Audiometer

Audiometer w/ Cntra-Mask
Wednesday, September 9, 1992 2:59 PM

Page 1

Front Panel

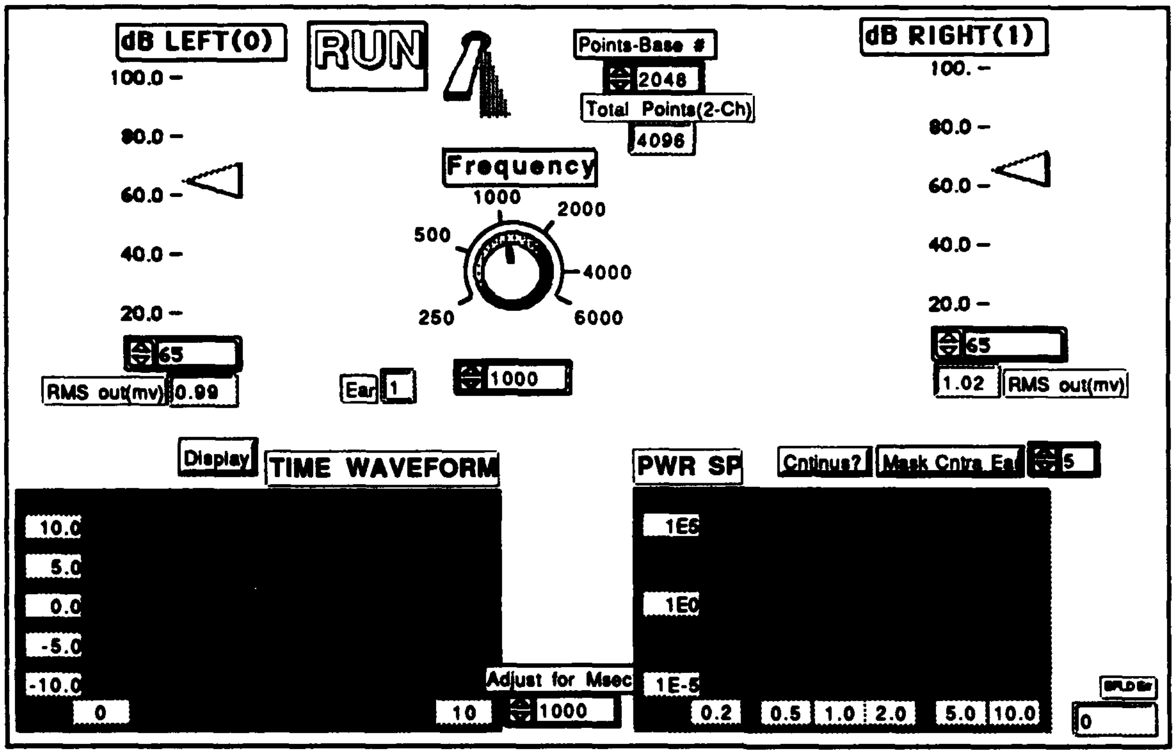


Figure A-1. Front Panel of Virtual Audiometer. The switch settings show that a frequency of 1000 Hz, at 65 dB (re 1 mV) is present at the right earphone. The **PWR SP** shows a single peak at 1.0 kHz and the **TIME WAVEFORM** is shown at the lower left. The tone is delivered alternately to the right and left earphones. No masking noise is present.

Block Diagram

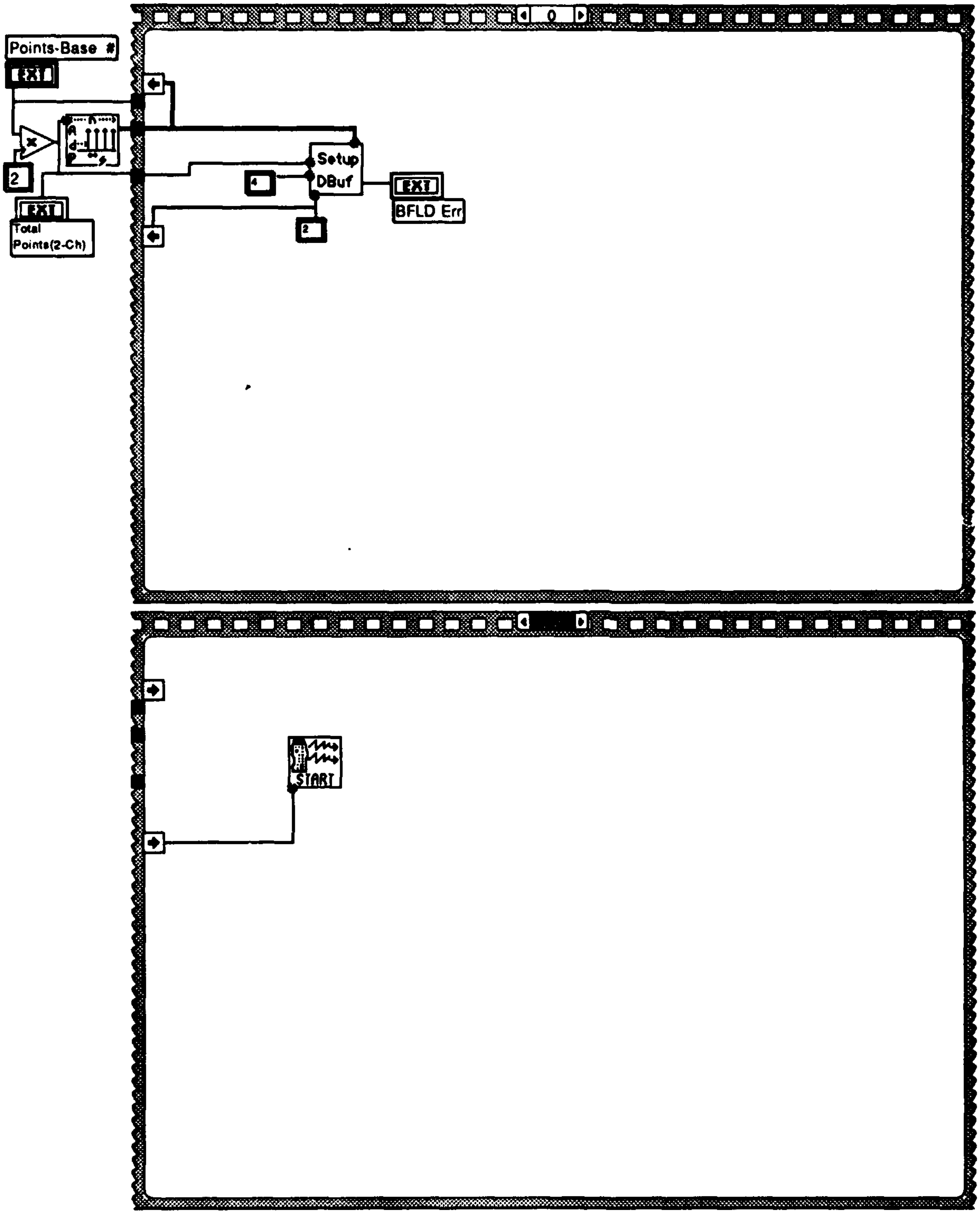
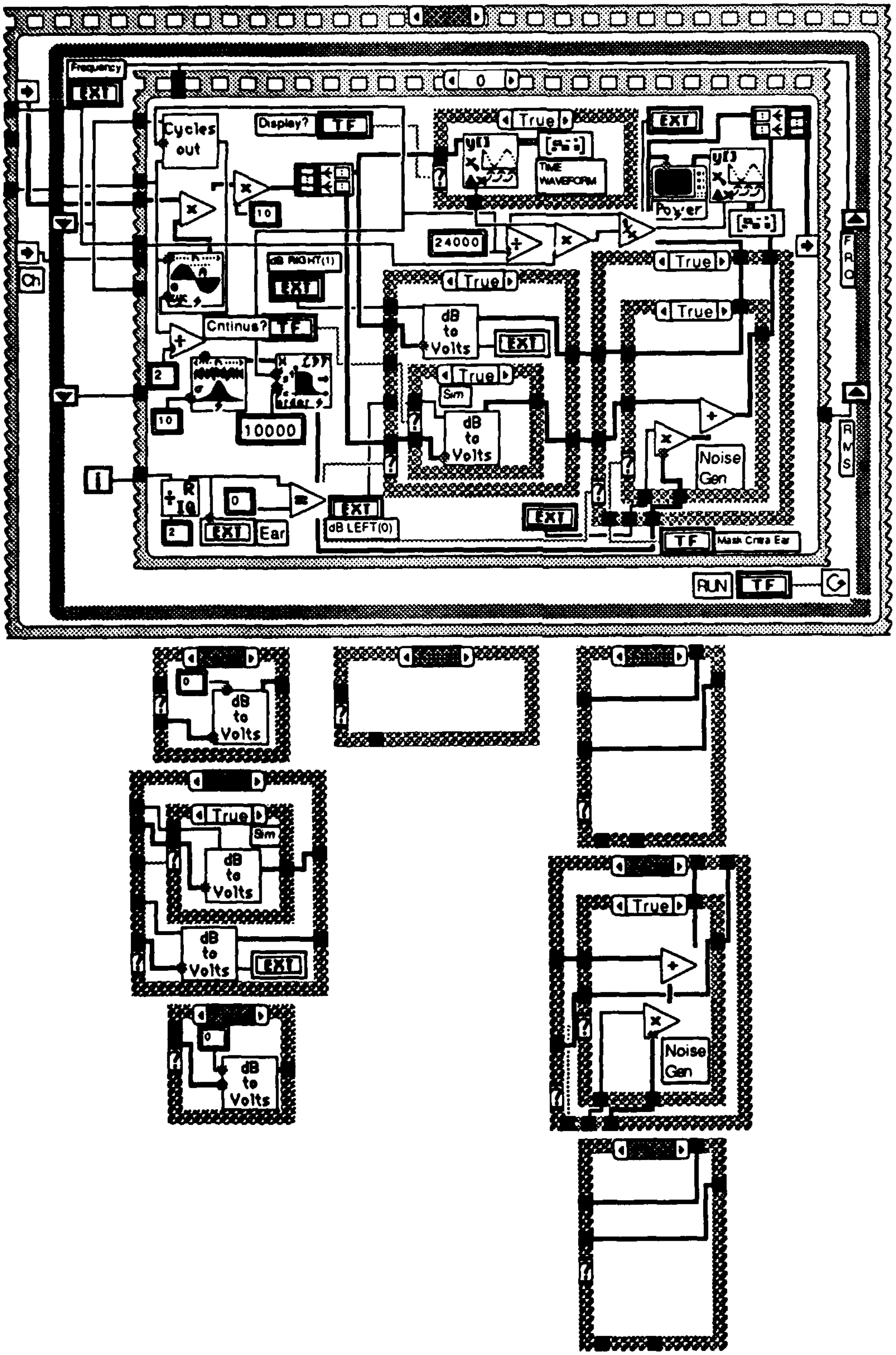


Figure A-2. Outer Frames 0 and 1 of Virtual Audiometer. Explanation is developed in text.



igure A-3. Outer Frame 2, While Loop, Inner Frame 0 and case statements for Virtual Audiometer. True cases are shown within Outer Frame 2, false and subsequent true cases are shown below. Explanation is developed in text.

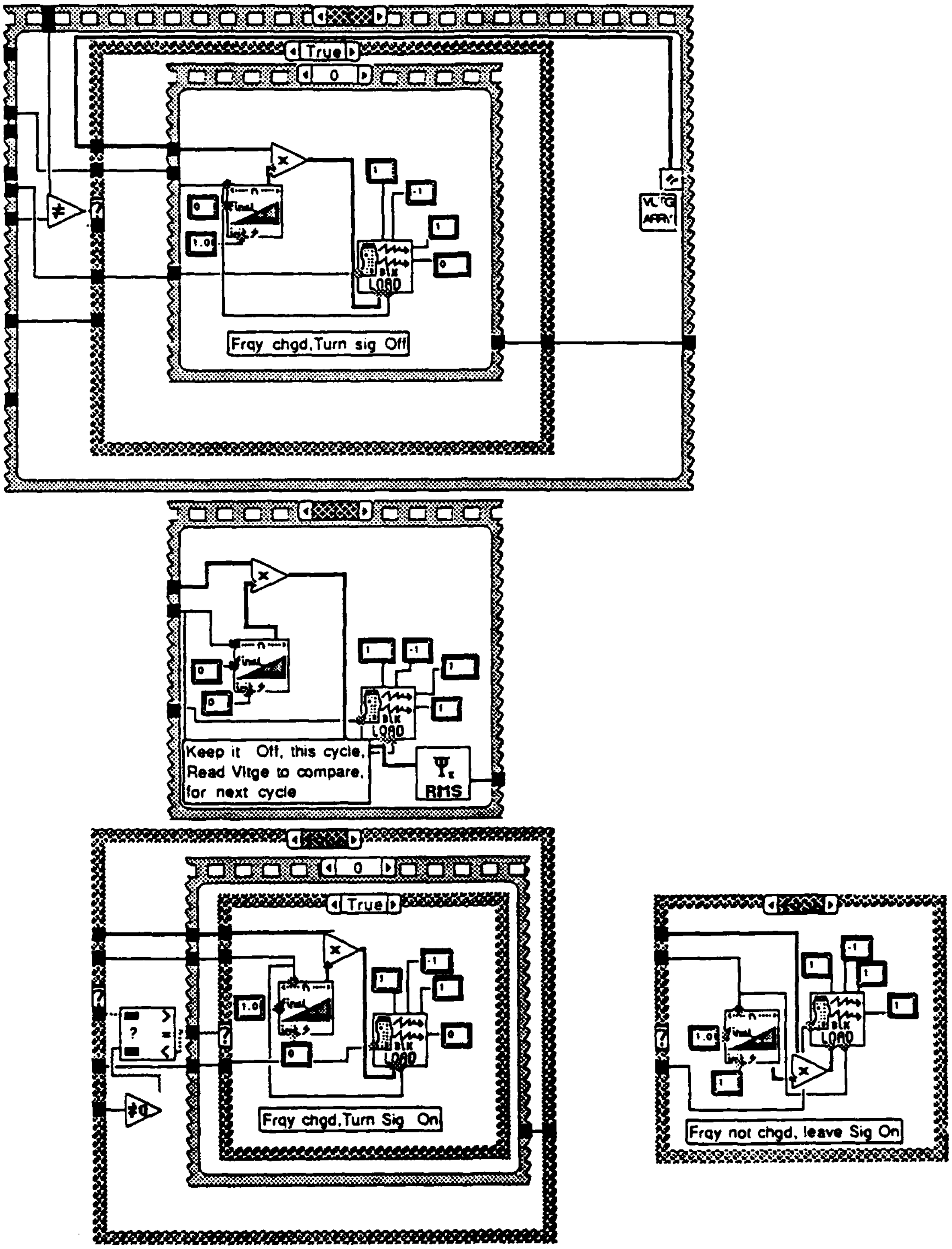
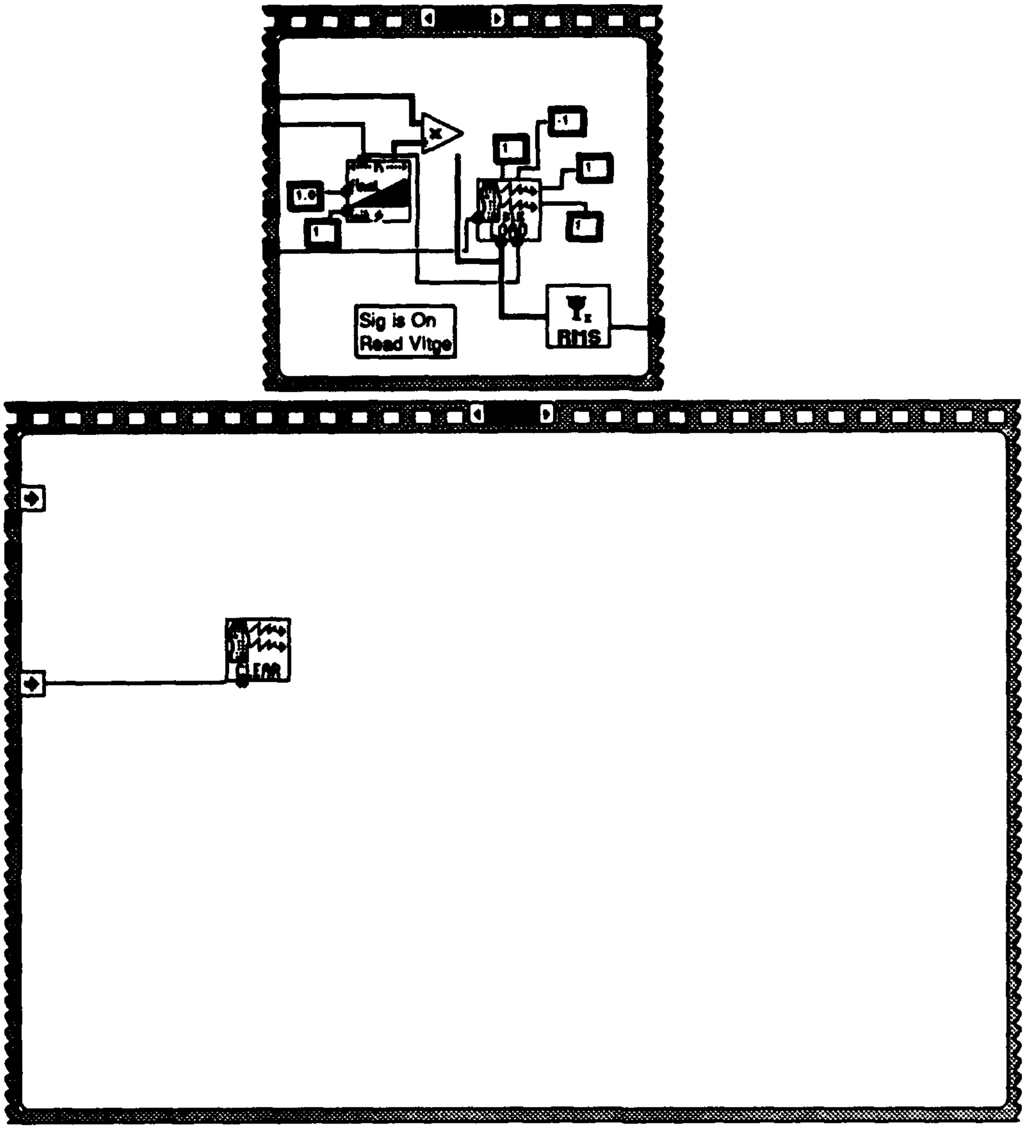


Figure A-4. Inner Frame 1, case statements and subsequent frames for On-Off control of acoustic stimulus. Explanation in text.



ᐧ**igure A-5.** Completion of Inner Frame 1 functions (upper) and Outer Frame 3 (CLEAR) of Virtual Audiometer.

APPENDIX B

Audiometric Data for Four Subjects

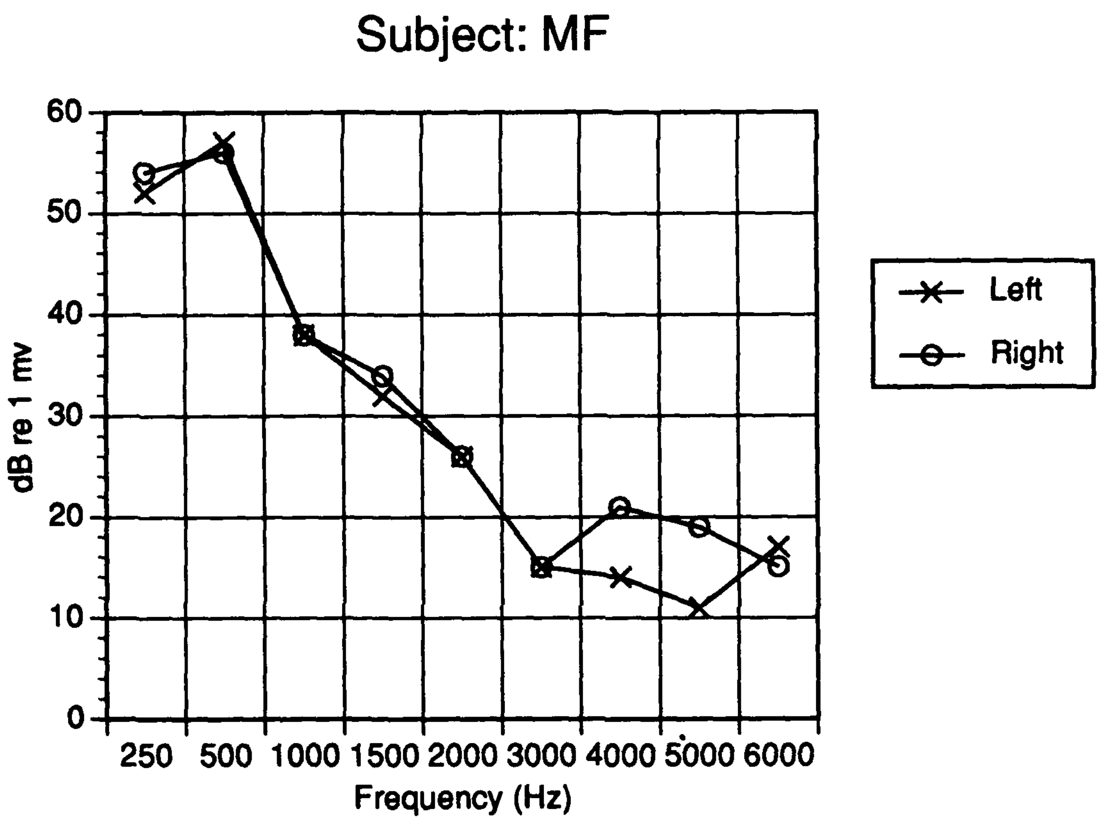
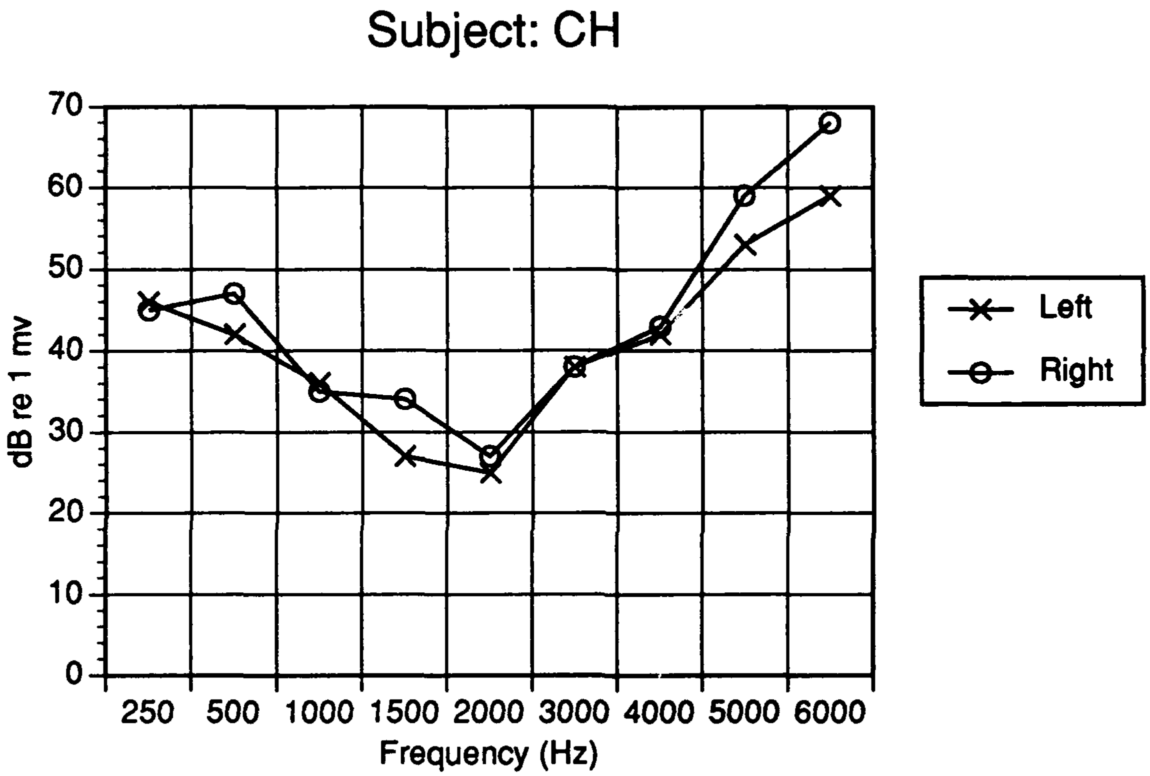
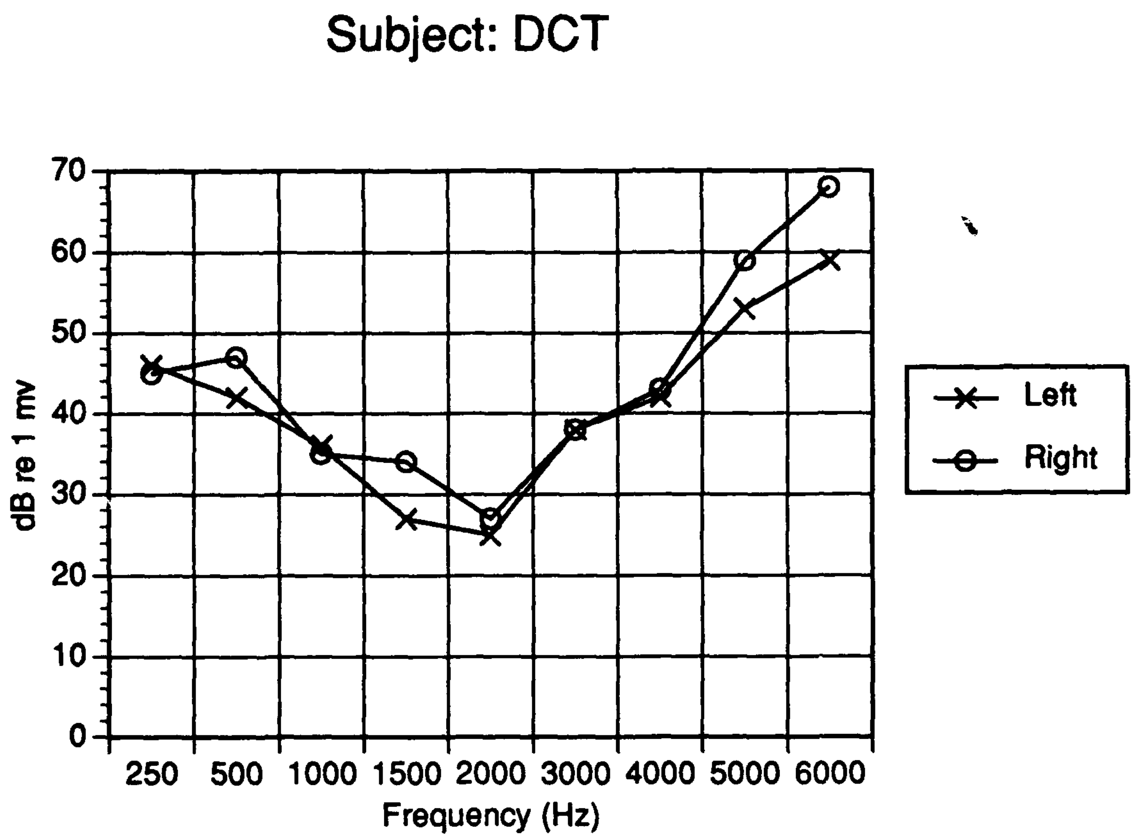


Figure B-1. Auditory thresholds (in office environment) at frequencies shown on abscissa for young female subject.



igure B-2. Similar to B-1, also for young female subject.



gure B-3. Similar to B-1, but for male subject, age greater than 50 years.

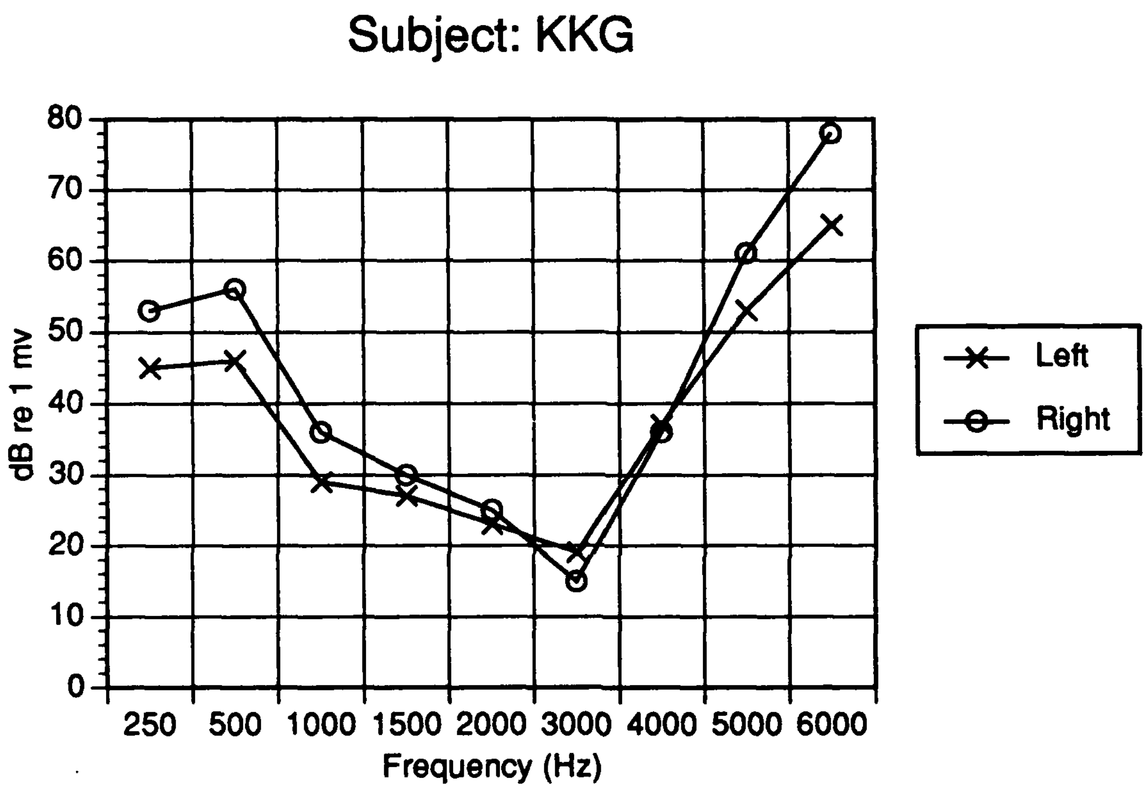


Figure B-4. Similar to B-3, but for second male subject.

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